NAVY DEPARTMENT

DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

AERODYNAMICS

STRUCTURAL MECHANICS

APPLIED MATHEMATICS

HYDROSTATIC PRESSURE TESTS OF AN UNSTIFFENED CYLINDRICAL SHELL OF A GLASS-FIBER REINFORCED EPOXY RESIN

[redacted]

John G. Pulos and John E. Buhl, Jr.

STRUCTURAL MECHANICS LABORATORY
RESEARCH AND DEVELOPMENT REPORT

April 1960 Report 1413

PRNC-TMB-648 (11-56)

HYDROSTATIC PRESSURE TESTS OF AN UNSTIFFENED CYLINDRICAL SHELL OF A GLASS-FIBER REINFORCED EPOXY RESIN

by

John G. Pulos and John E. Buhl, Jr.

April 1960

Report 1413
S-F013 0302

ABSTRACT

An unstiffened cylindrical shell of 32.67-in. mean diameter, built up of layers of an epoxy resin tape reinforced with glass fibers, was tested to collapse under external hydrostatic pressure. The shell structure failed at a pressure of 3735 psi, which is in good agreement with the pressure calculated from the elastic shell-buckling equations of von Mises. A longitudinal tear accompanied by some delamination of the layers was observed over the entire length of the cylinder.

INTRODUCTION

Presently, the U.S. Navy is investigating the use of reinforced plastics for shell structures subjected to external hydrostatic pressure. Interest in these materials has been stimulated by virtue of their apparent favorable strength-weight properties, corrosion resistance, nonmagnetic characteristics, high electrical resistivity, and efficient sonar and radio-wave transmission. Only limited data[1*] are available on the structural response of shell structures made of glass-fiber reinforced plastics and subjected to pressure loadings.

In April 1959 the Zenith Plastics Company of Gardena, California, a subsidiary of Minnesota Mining and Manufacturing Company, proposed to the Office of Naval Research the possible application of plastic materials developed by the parent company to a variety of plate and shell structures of interest to the U.S. Navy. Subsequent conferences arranged by the Office of Naval Research and attended by cognizant personnel of Zenith, the Office of Naval Research, the Bureau of Ships, and the David Taylor Model Basin led to the establishment of a joint program of exploratory research to study the feasibility of using such materials in cylindrical shell structures.

---

* References are listed on page 14.

A relatively large-size unstiffened cylindrical shell was fabricated by Zenith at their own expense and forwarded to the Model Basin for instrumentation and testing.

A description of the plastic cylinder, test procedure, and discussion of results obtained are presented herein.

DESCRIPTION OF TEST CYLINDER

The test cylinder had a mean diameter of 32.67 in., a wall thickness of 1.61 in., an overall length of 59.0 in., and a weight of 11.57 lb/in. of length. The ends of the plastic cylinder were closed by heavy steel plates machined to fit the inside of the cylinder and held together by a tie rod. The closure plates reduced the effective length of the test section to 55.0 in. The overall dimensions were dictated by the size and capacity of the Model Basin test facilities and the existence of a 31.06-in.-diameter mandrel at Zenith. A schematic diagram showing the cylinder in the test tank is given as Figure 1.

The cylinder was fabricated by winding a glass-fiber-reinforced epoxy resin tape* on the mandrel. The laminates consisted of two layers of 2-in.-wide tape with the glass fibers oriented in the circumferential direction and one layer of 12-in.-wide sheets having the glass fibers oriented in the longitudinal direction. This sequence of complete dispersion of layers was repeated until the required thickness of 1.61 in. was obtained, ending with two circumferential layers on the outside surface.

Nominal mechanical properties of the cured material as used in the test cylinder were furnished by the manufacturer:

Density, 0.070 lb/cu in.

Yield strength in circumferential direction σ_ϕ, 70,000 psi

* "Scotchply" Type XP-125, a patented product of Minnesota Mining and Manufacturing Company.

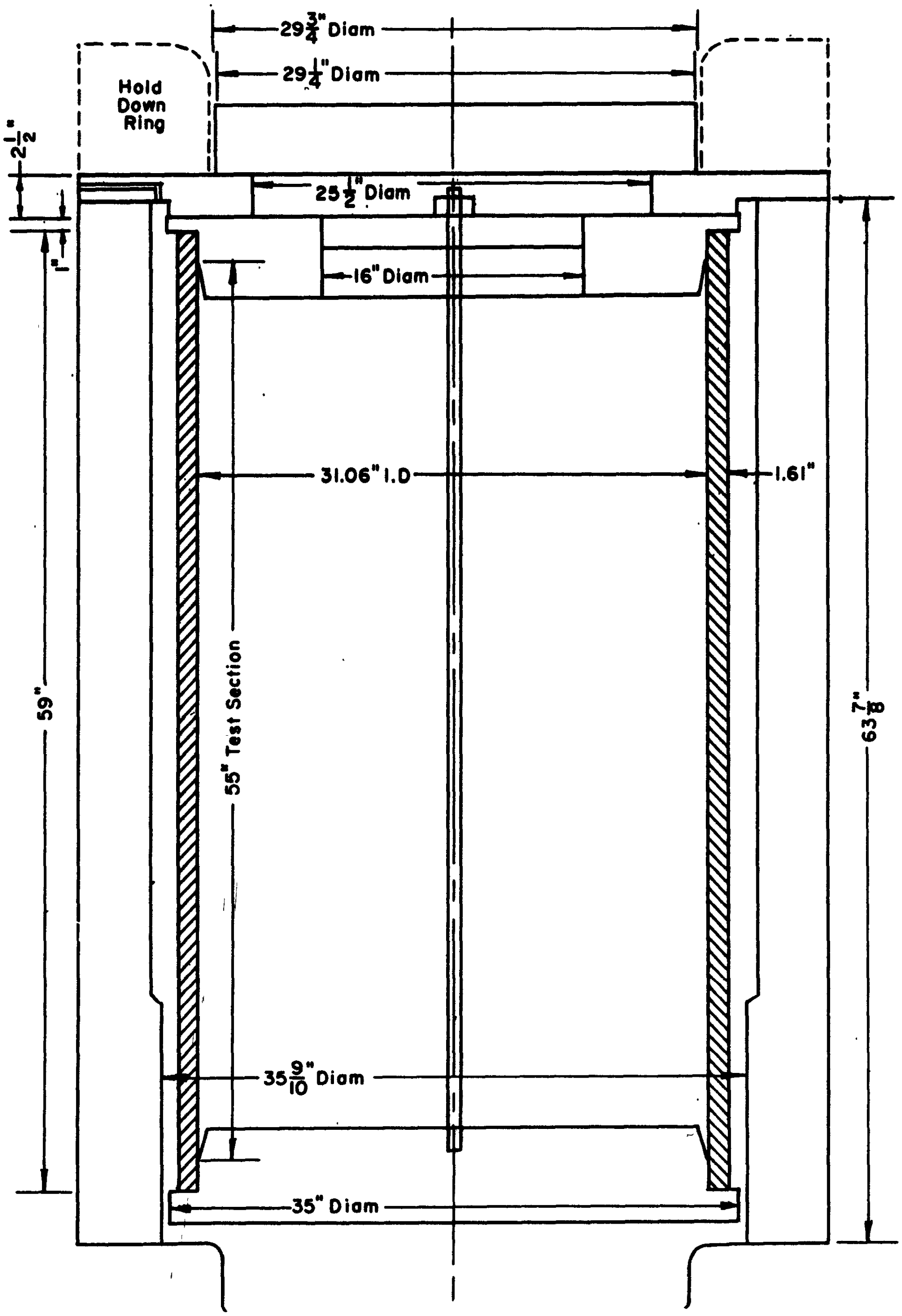


Figure 1 - Schematic Diagram of Cylinder ZP-3562 in 37-Inch Test Tank

Modulus of elasticity in circumferential direction

E_ϕ, 4.8×10^6 psi

Poisson's ratio ν, 0.1

INSTRUMENTATION AND TEST PROCEDURE

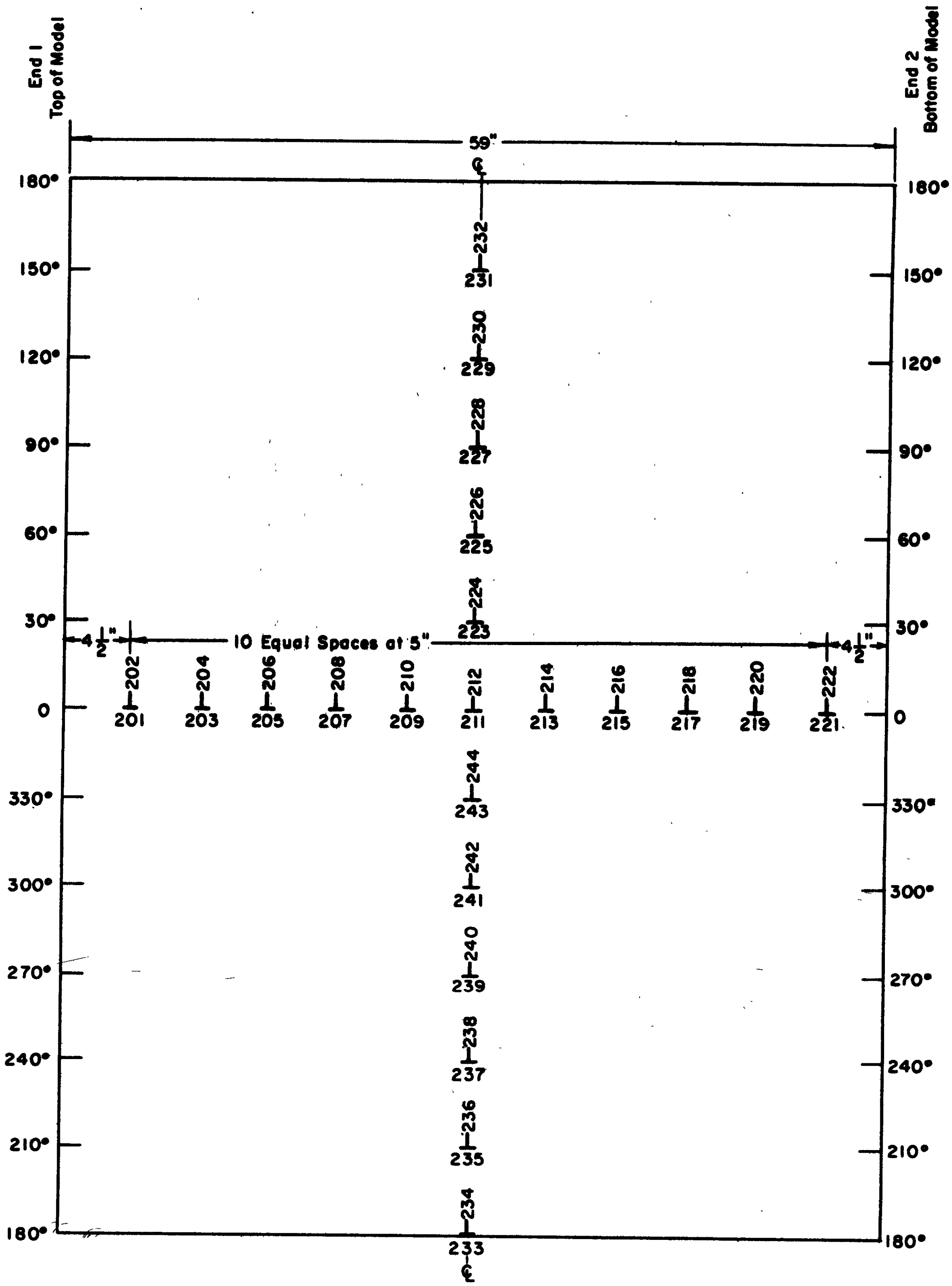
Strain-gage rosettes of the AX-5-1 type were placed in longitudinal and circumferential arrays as shown in Figure 2 to investigate the displacement and strain distributions in the cylinder. Gages from the same lot were applied to specimens of the cylinder material for temperature compensation purposes.

The test cylinder was loaded by external oil pressure up to 3000 psi in the Model Basin 37-in. pressure tank. Prior to loading, the cylinder was completely filled with oil so that the volume change during deformation could be measured. The test was conducted in two runs. During these pressure runs the strains and internal-volume changes of the cylinder were recorded.

In Run 1 pressure was increased from 0 to 1500 psi in 100-psi increments. The 1500-psi pressure was maintained for 37 min and then pressure was reduced to zero. For Run 2 pressure was increased from 0 to 1500 psi in 300-psi increments (each held for about 15 min), from 1500 to 2500 psi in 100-psi increments (each held for about 10 min), and from 2500 to 3000 psi in 50-psi increments (each held for about 10 min).

After the initial loading to 3000 psi, the pressure was reduced to 2400 psi and maintained there for 15 hr. The pressure was then raised to 2800 psi and maintained for 5 hr followed by 18 hr at 3000 psi. The strains were recorded hourly while the various pressures were maintained to detect any propensity for the plastic cylinder to creep.

When the tests at the Model Basin were completed, the test cylinder was loaded to failure in the Naval Research



I Circumferential Gages (Even Numbered) Outside Gages 200 Series

— Longitudinal Gages (Odd Numbered) Inside Gages 100 Series

Figure 2 - Gage Location Diagram

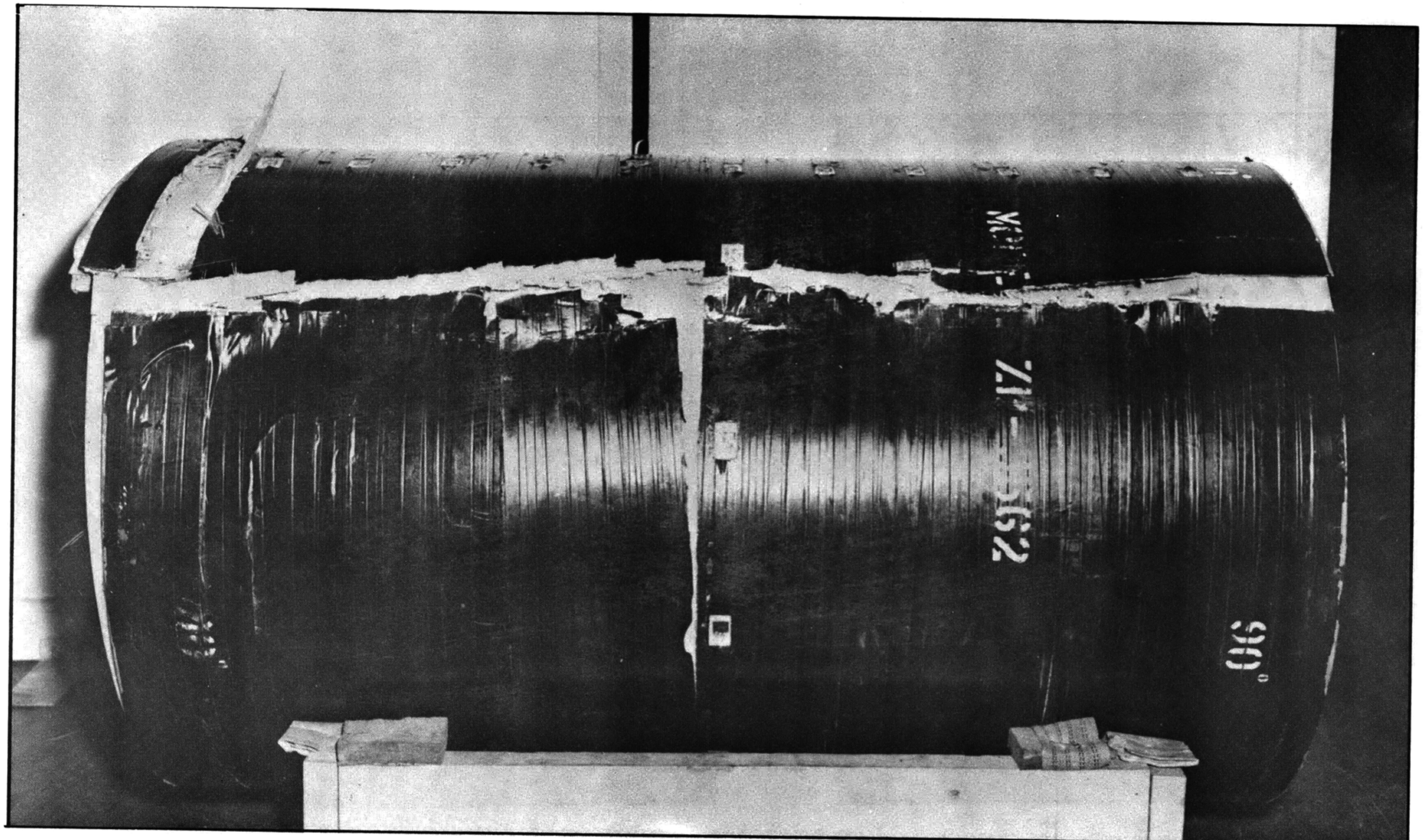
Laboratory 4-ft-diameter test tank. These latter tests were also conducted in two pressure runs: the first to 3030 psi which was held for approximately 15 min and after complete unloading the second was to collapse. For the second run an initial pressure of 3000 psi was applied to the cylinder and held for 5 min, after which the pressure was raised in increments of 25 psi. The pressure was held for 2 min at each 25-psi increment and for 5 min at each 100-psi increment.

TEST RESULTS AND DISCUSSION

The cylinder collapsed at a pressure of 3735 psi after having sustained a pressure of 3750 psi for approximately 2 min. The 15-psi drop in pressure was primarily due to a small leak in a pressure fitting in the Naval Research Laboratory test tank. When failure occurred, the cylinder split longitudinally at the 35-deg generator accompanied by some circumferential tearing at midlength and considerable delamination in the wall thickness as shown in Figure 3.

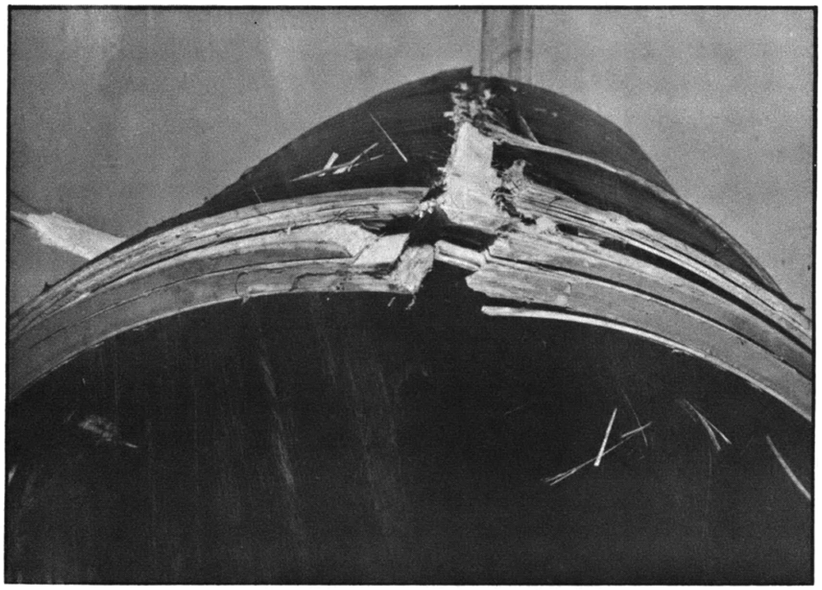
The collapse pressure of 3735 psi is in good agreement, within 6 percent, with the pressure of 3960 psi calculated from the elastic shell buckling equation of von Mises for the case of simply supported edges and given as Equation [9] in Reference 2. This agreement is not at all surprising because the material in the cylinder is strictly linearly elastic right up to the fracture strength. The agreement is certainly well within the accuracy of the effective Young's modulus for such an anisotropic material.

The strain-sensitivity factors for each gage, determined from Run 2, are listed in Table 1. All gages showed compressive strain. Pressure-strain plots for the gages located near the generator of the cylinder where failure occurred are shown in Figure 4. The stresses at each gage location were calculated from the total strains measured at 3000 psi and a Young's modulus $E = 4.8 \times 10^6$ psi and a Poisson's



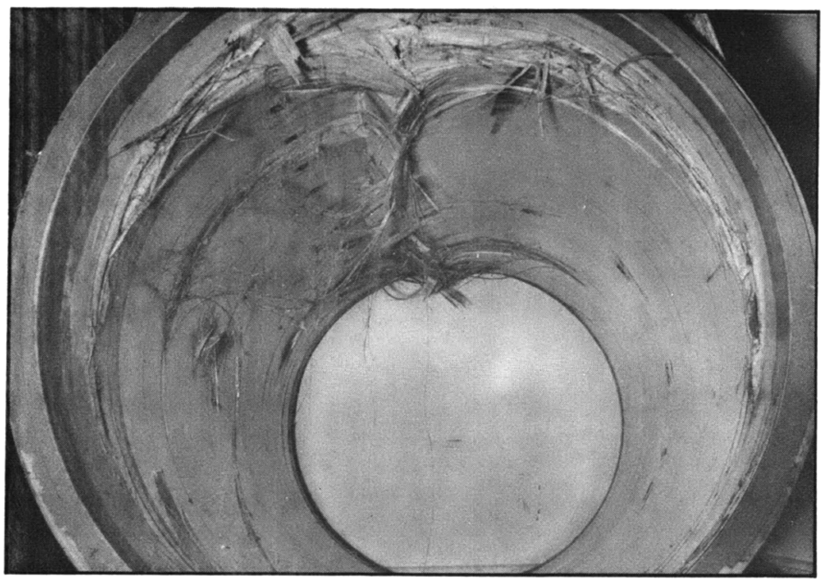
PSD 98499

Figure 3a - Overall View



PSD 98494

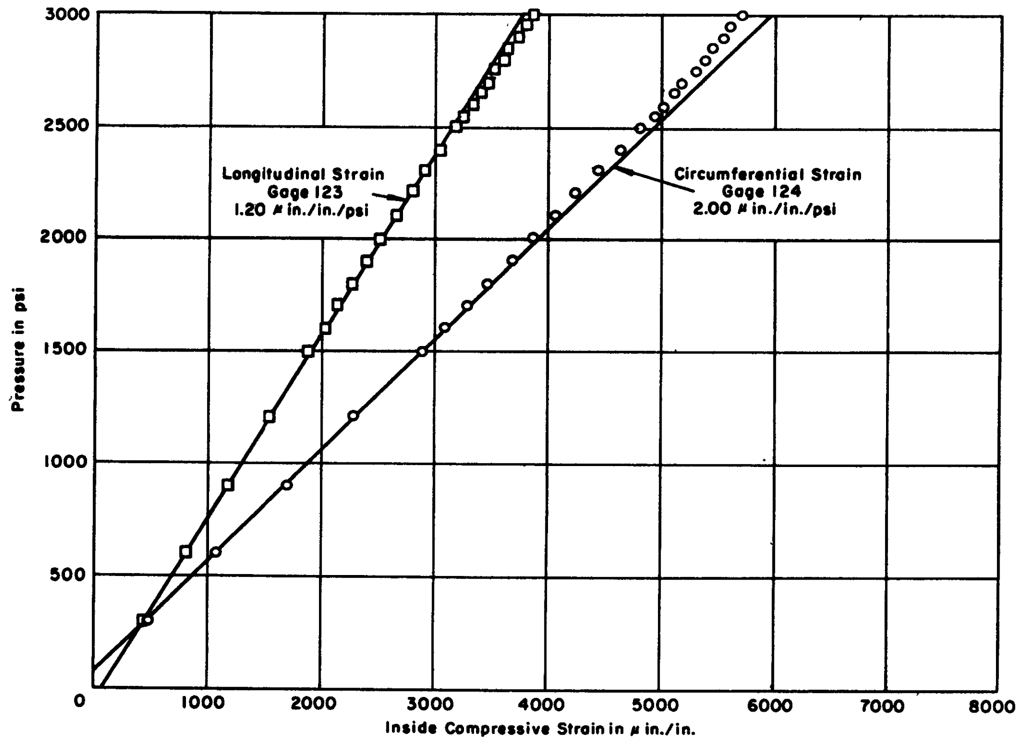
Figure 3b - Bottom-End View



PSD 98495

Figure 3c - Inside View

Figure 3 - Cylinder ZP-3562 after Failure



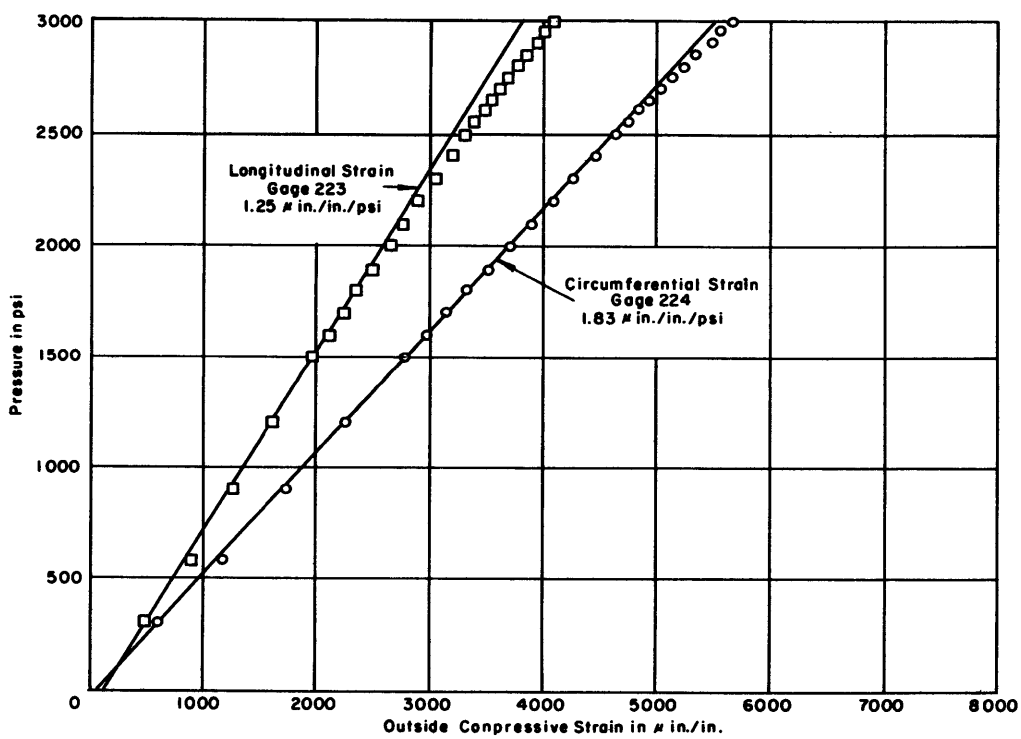


Figure 4 - Pressure-Strain Plots for Gages Located on 30-Degree Generator at Middle of Cylinder from Run 2

TABLE 1

Strain-Sensitivity Factors in Compression from Run 2

Gage	Sensitivity µin/in/psi Inside Surface		Gage	Sensitivity µin/in/psi Outside Surface	
	Long.	Circum.		Long.	Circum.
Longitudinal Distribution					
101	1.04	--	201	1.66	--
102	--	1.10	202	--	0.98
103	0.80	--	203	1.72	--
104	--	2.06	204	--	1.84
105	1.22	--	205	1.27	--
106	--	2.06	206	--	1.85
107	1.25	--	207	1.16	--
108	--	2.03	208	--	1.77
109	1.24	--	209	1.32	--
110	--	1.96	210	--	1.78
111	1.20	--	211	1.20	--
112	--	2.00	212	--	1.72
113	1.23	--	213	1.29	--
114	--	2.03	214	--	1.80
115	1.25	--	215	1.06	--
116	--	2.05	216	--	1.74
117	1.18	--	217	1.25	--
118	--	2.06	218	--	1.85
119	0.72	--	219	1.60	--
120	--	2.05	220	--	1.79
121	0.92	--	221	1.64	--
122	--	1.07	222	--	0.92
Circumferential Distribution					
111	1.20	--	211	1.20	--
112	--	2.00	212	--	1.72
123	1.20	--	223	1.25	--
124	--	2.00	224	--	1.83
125	1.20	--	225	1.20	--
126	--	2.05	226	--	1.72
127	1.17	--	227	0.97	--
128	--	2.06	228	--	1.41
129	1.20	--	229	1.17	--
130	--	2.06	230	--	1.65

TABLE 1 (continued)

Gage	Sensitivity μin/in/psi Inside Surface		Gage	Sensitivity μin/in/psi Outside Surface	
	Long.	Circum.		Long.	Circum.
Circumferential Distribution					
131	1.21	--	231	1.14	--
132	--	2.05	232	--	1.75
133	1.17	--	233	1.22	--
134	--	1.98	234	--	1.75
135	1.18	--	235	1.12	--
136	--	2.00	236	--	1.78
137	1.20	--	237	1.09	--
138	--	2.05	238	--	1.70
139	1.16	--	239	1.05	--
140	--	2.07	240	--	1.68
141	1.06	--	241	1.14	--
142	--	2.13	242	--	1.68
143	1.21	--	243	1.17	--
144	--	2.08	244	--	1.66
Average	1.18	2.04		1.14	1.69

ratio $\nu = 0.1$. The maximum stress thus found was a circumferential compressive stress of 33,000 psi on the inside fiber at midlength. Extrapolating this stress to the collapse pressure of 3735 psi gives a calculated stress of 41,500 psi, as compared with a material strength of 70,000 psi.

The only significant data from the internal-volume measurements were those obtained from Run 2. The change in volume with pressure for this run is shown in Figure 5. It should be noted that the curve is essentially linear up to approximately 1800 psi.

While the pressure of 3000 psi was maintained for the 18-hr period, the maximum observed change in strain was that of Gage 202, located near the end closure bulkhead. The indicated compressive strain changed less than 5 percent, from 3100 μin/in to 3250 μin/in. These measurements indicate that

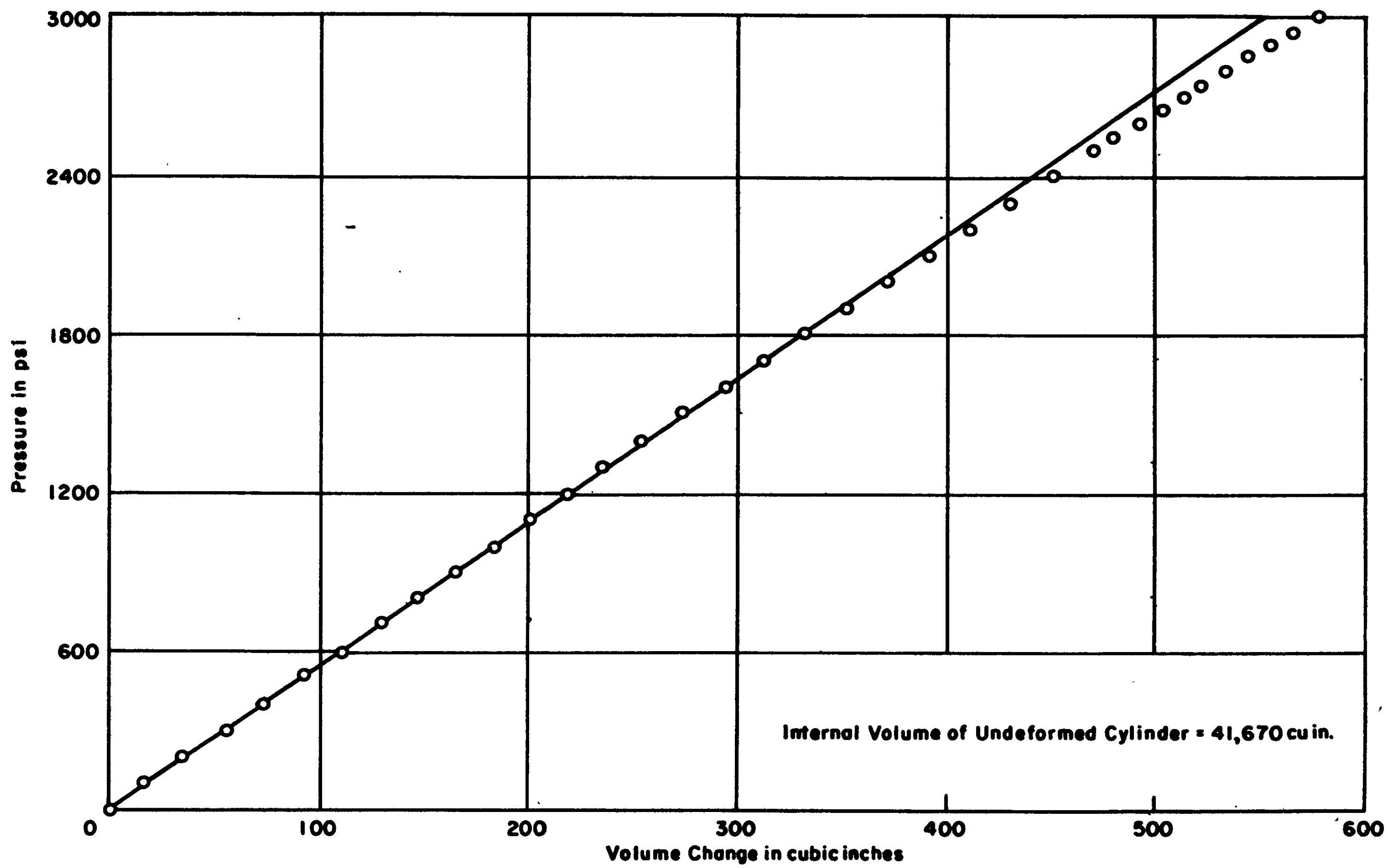


Figure 5 - Pressure-Volume Measurements from Run 2

creep is of no consequence for this pressure level and time duration.

CONCLUSIONS

1. The collapse pressure of the unstiffened cylinder (ZP-3562) is 3735 psi.

2. The maximum stress at the collapse pressure is only 60 percent of the strength of the material.

3. The test cylinder appears to have failed primarily by elastic instability rather than by overstressing of the shell material. The large buckling deformations caused the material to fracture.

4. The recorded maximum creep of the material under a pressure of 3000 psi, or 80 percent of the collapse pressure, was 5 percent for an 18-hr load application.

RECOMMENDATIONS

1. It appears that the collapse pressure of the test cylinder can be increased by about 50 percent by redesigning it as a ring-stiffened cylinder with the same weight. This should be investigated experimentally.

2. The resistance of cylindrical shells made of this material to dynamic loads should be investigated experimentally.

3. The effect of creep on the collapse strength of cylindrical shell structures made of this material should be investigated experimentally by maintaining pressures corresponding to stress levels on the order of about 75 percent of the fracture strength of the material for minimum test periods of several days.

ACKNOWLEDGMENTS

The cooperation of the Sound Division of the Naval Research Laboratory, in particular Messrs. Walter Wastfield and Nicholas Laios, is greatly appreciated.

REFERENCES

1. Barnet, F.R. and Lloyd, C.L., "Reinforced Plastics in the Construction of External Pressure Vessels," Society of Plastics Engineers Journal, August 1956, pp. 15-19.

2. Windenburg, D.F. and Trilling, C., "Collapse by Instability of Thin Cylindrical Shells under External Pressure," David Taylor Model Basin Report 385 (Jul 1934).

INITIAL DISTRIBUTION

Copies	
14	CHBUSHIPS 3 Tech Info Br (Code 335) 1 Tech Asst to Chief (Code 106) 2 Mat Dev Sec (Code 342) 1 Prelim Des Br (Code 420) 1 Prelim Des Sec Code 421) 1 Ship Protec Sec (Code 423) 1 Hull Des Br (Code 440) 2 Sci & Res Sec (Code 442) 1 Struct Sec (Code 443) 1 Submarine Br (Code 525)
2	CHONR, Mech Br (Code 439)
1	CNO (Op 373)
1	CDR, USNOL
1	DIR, USNRL, Attn: TID (Code 2027)
1	NAVSHIPYD PTSMH
1	NAVSHIPYD MARE
1	NAVSHIPYD NORVA, Attn: UERD (280)
1	CDR, USNOTS, China Lake
2	CHBUDOCKS, Attn: C-423
1	CHBUWEPS
2	Zenith Plastics Company, Gardena, Calif.